Is [Scalable] Digital Preservation Possible?

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What is Lossless Preservation?

- Digital preservation based on the assumption that preserved objects will be “bit perfect”
  - The same bits as were stored, in the same order
  - Any object not stored perfectly can be discarded
  - Low rates of loss, lower rate of “silent corruption”
- Antientropy: Preserving bits as an active process
  - Multiple *decorrelated* copies
  - Data “scrubbing” and repair
  - Reliable determination of correctness

Lossless Preservation Requirements

- Implementing losslessness
  - Periodic migration of media, formats and tools
  - Cheap, high density media, cycles, bandwidth
  - Fast, high fidelity data copying and movement
- Maintaining losslessness
  - Sufficient decorrelation or control to rule out loss
  - Continuity of: organization, funding, competence
  - Nonbalkanization

Approaches to Lossless Preservation

- Tapes in a Cave (Portico)
  - Small degree of replication (3 or less)
  - Highly controlled environment
  - Limited fault model
- Lots of Copies Keeps Stuff Safe (LOCKSS)
  - High degree of replication
  - Loosely controlled environment
  - Byzantine fault model (voting)

Lessons Learned From David Rosenthal

- Decorrelate, decorrelate, decorrelate!
  - Don't count on organizations
  - Don't count on funding
  - Don't count on politics
  - Don't count on public interest
  - Don't count on academic integrity
- The largest cause of data loss is operator error
- But LOCKSS has only one implementation
  - It's very complicated!

Lossless Preservation Reconsidered

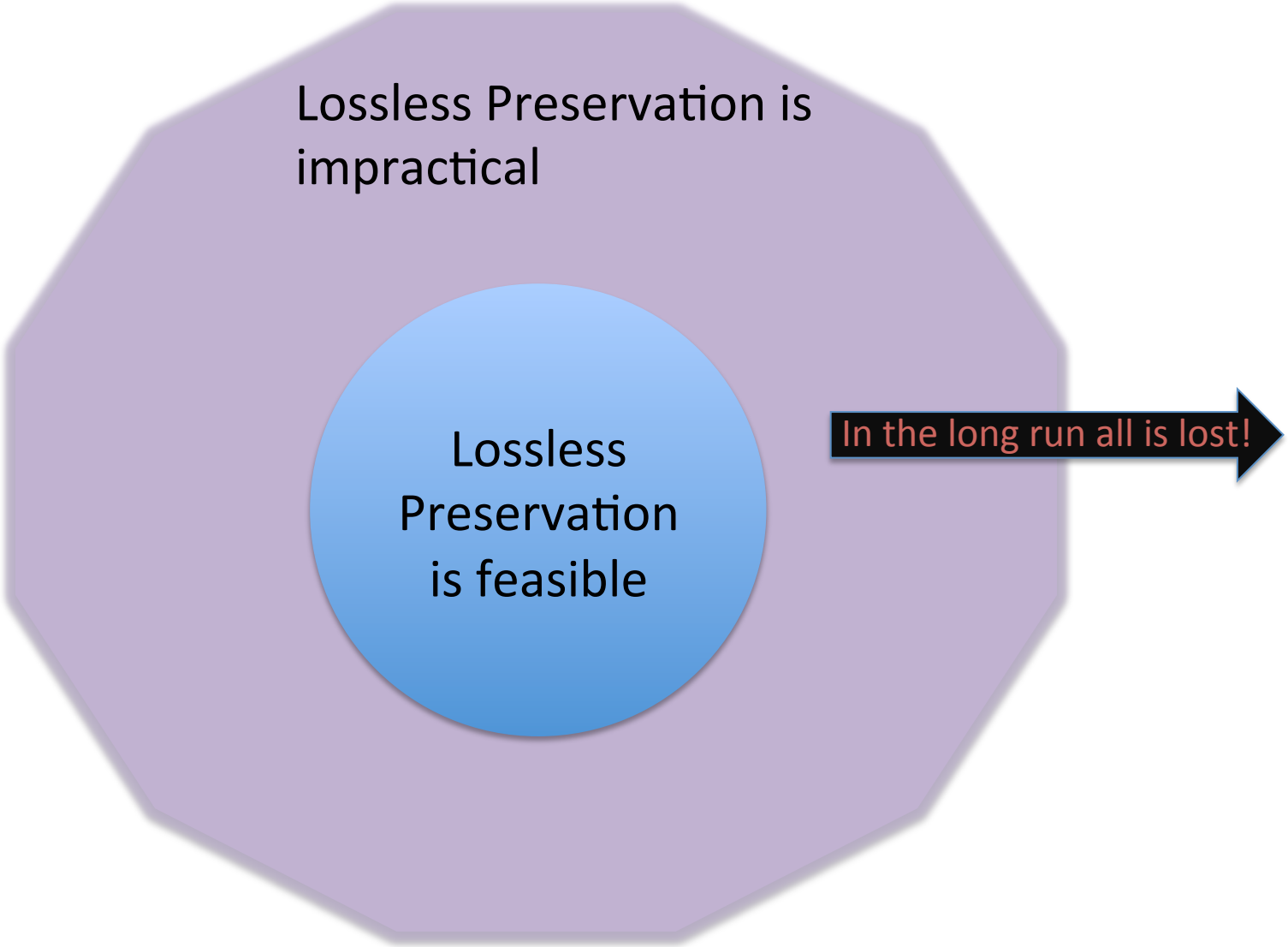
- Eventually, all assumptions are violated
- Distributed systems don't have rock-solid stability
- Software maintenance is both necessary and dangerous (error-prone)
- Information loss is a one-way street
- Difficult, active processes are expensive
- Values and priorities are difficult to agree on, change over time

Scalability Issues in Lossless Preservation

- We can't preserve everything
  - The requirements of losslessness impose limits
- Archive quality is a function of the weakest link in the "process" of preservation
  - Longer duration means greater likelihood of loss
- Lots of difficult steps lead to a stumble
  - Scalability requires fewer, simpler steps

The Limits of Losslessness

Requirement Dimensions: Size, Time, Access …



Lossy Preservation: Cheaper & Easier?

- The Lossy Assumption
  - Some preserved objects may experience unrecoverable errors in bit preservation
  - Analogy to lossy compression
- Can Lossy Preservation Be More Scalable?
  - Less active antientropy (leave that data alone!)
  - Use of highly stable media (perhaps not as fast)
- But how would Lossy Preservation work?

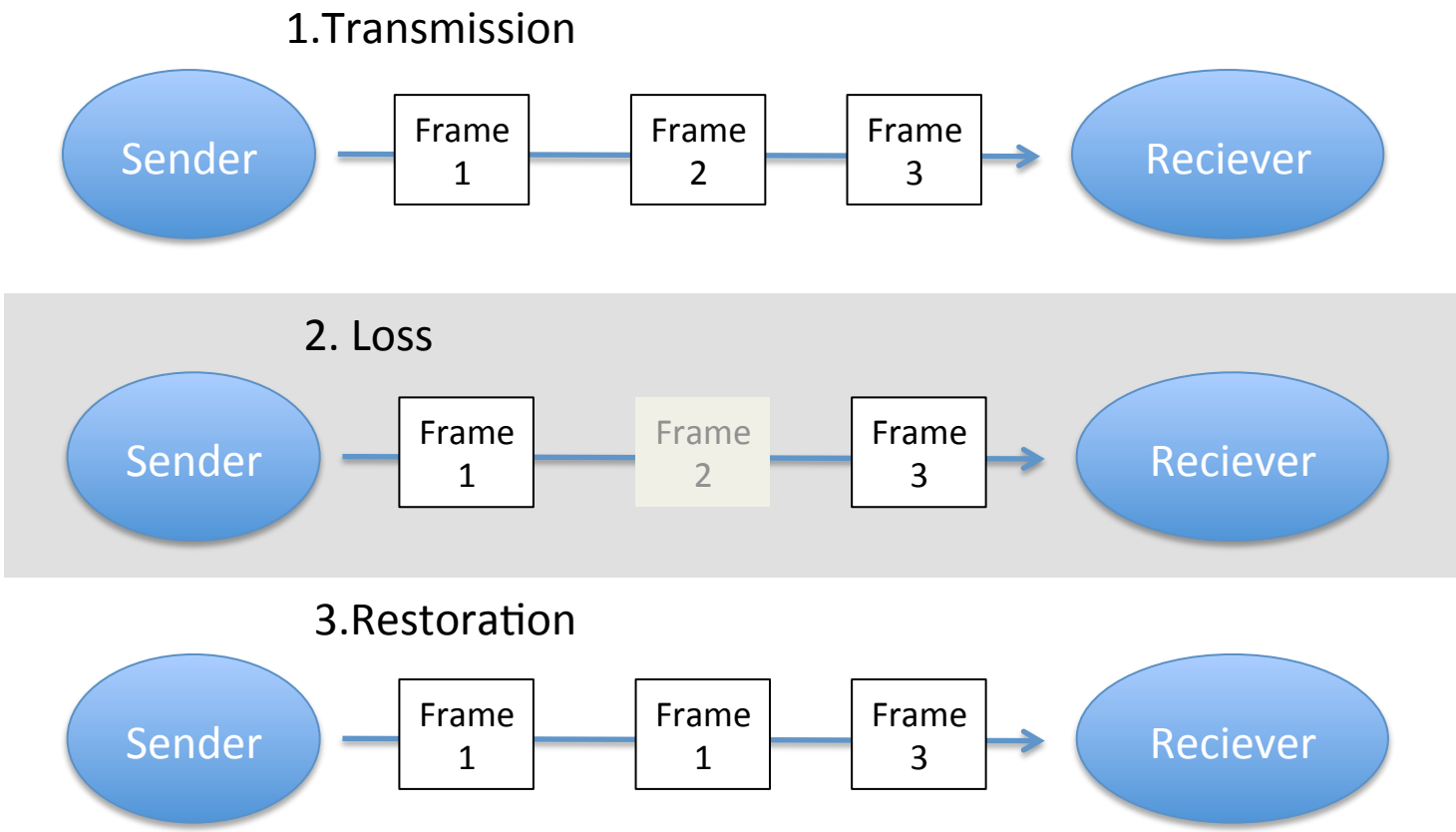
Communicating on a Noisy Channel

- If the sender is available & faultless, errors detected by the receiver may be addressed by *retransmission*.
  - Retransmission increases latency.
  - What if the sender is faulty or unavailable?
- *One-way* communication
  - "Fire and forget": no control loop prior to receipt.

An Example: One-Way Video Streaming

- Retransmission latency may be too high
- There may be too many receivers (multicast)
- The received stream may have errors
- One-way solution: application level resilience
  - Isolated corrupted frames can be detected and
  - replaced by interpolation (copy adjacent frame)
- The result may be usable *for some purposes*
  - Knowledge of structure and application are used

An ounce of cure ...



Data Preservation as One-Way Communication Over Time

- The sender is not available, no retransmission
- Lossy preservation creates a noisy channel
- Higher level knowledge can be used
  - Digital Archeology/Forensics
  - Use the structure of the data
  - Target application requirements
- A form of End-to-End design borrowed from scalable network (Internet) architecture

Issues in Lossy Preservation

- Substantial probability of modified bits
  - Lossless techniques can be used when lower levels of scalability will suffice
  - Lossless and lossy techniques can work together
- Requires application of higher-level knowledge, assumptions about future applications
- It may not solve all the problems addressed by lossless preservation (tamper-resistance)

A Case for Lossy Preservation

- Some data is really large
  - Earth observing satellites
  - Sensor networks
  - Continuous media capture
- Some data is of unknown value
- Forever is a *really* long time
- We need to *maximize* the chance of preserving usable knowledge in digital form

Example 1: Video Preservation

- The technique used in one-way video streaming can be applied to lossy preservation
  - To watch a preserved video with errors, delete bad frames and interpolate
  - What about file headers?
- Other approaches are also possible
  - A restoring algorithm might learn stable features such as the faces of actors and recreate them
  - An application interested in analyzing the use of camera angles might be inherently more robust

Example 2: Interleaved Text
(Chip Hawley's doctoral research)

- Failure model: Loss of contiguous blocks
- Use model: dictionary-based spelling correction of corrupted words
- Alternate formats:
  - Natural bit order

    0123 4567 0123 4567
  - Interleaved bit order

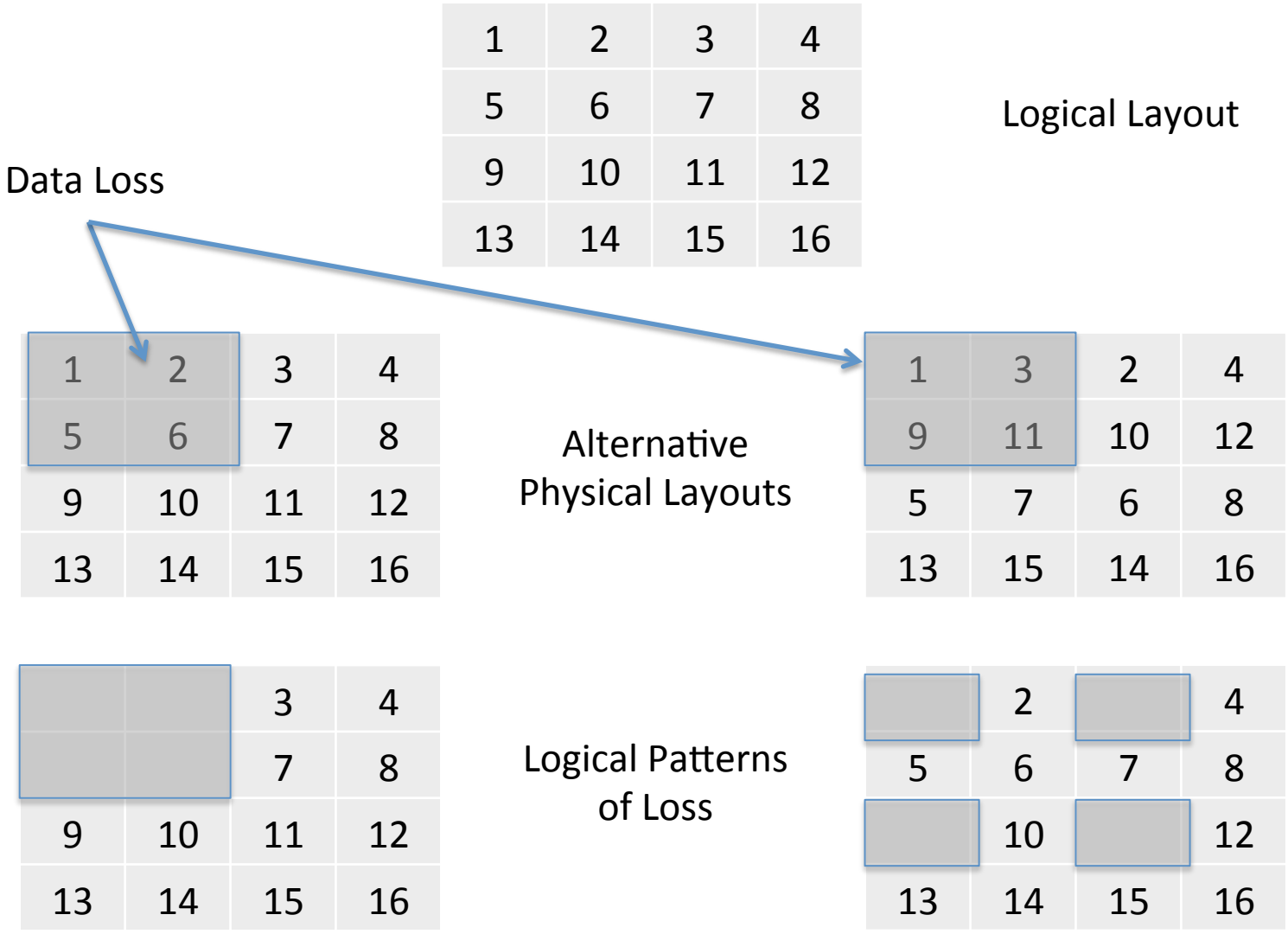
    0000 4444 1111 2222

    0123 4567 0123 4567 (reordered)

Example 3: Geospatial Data

- Satellite data has many variables per location
  - If a block of data is lost, is it better to lose it at one location or many layers at different locations?
  - Is it better to lose all the data from one variable or to spread the loss over many variables?
- Some aspects of the data do not change quickly while others are very volatile
- Some variables are more valuable than others

Managing Loss Through Layout



Example 4: Preserving Raw Data

- Consider an experiment that captured records of the form (date, temp, SatImage)
  - Date and temp are 32 bits each
  - SatImage is 100 GB
- Assume equal probability of failure for every bit in a record

Example 4: Using Raw Data

- Suppose that an analysis performed on this data 100 years later is very sensitive to temp
  - Errors in the temp field quickly invalidate results
  - But results are *highly* robust w.r.t. SatImage errors
- When we store the data, we must strive to minimize loss in the temp field (losslessness)
  - Perhaps resources utilization can be optimized by applying lossy techniques to the SatImage field

Planning for Loss of Data

- Once loss occurs it may be too late
  - Digital archeology can only do so much
- What is to be done?
  - Some formats are less vulnerable
    - Avoid headers and other internal dependences
  - Some storage media are less vulnerable
    - Disk head crashes can destroy contiguously stored data
    - Tape is relatively well-behaved
    - Good failure modes may trump speed and density

Research in Lossy Preservation

- We require a better understanding of the tradeoff between loss and scalability
- Can we optimize the interaction of failure modes, data formats, restoration algorithms and applications?
- We must explore the range of failure modes available in storage media & systems
- Object/document authentication must be reexamined in the face of loss.

The Digital Delusion

- Any process whose state is expressed in digital form can be implemented deterministically.
  - Delusion: False belief, misapprehension, fantasy
  - What about scalability issues: Cost? Difficulty? …
- Reality Bites: Addressing Data Corruption
  - Terascale file transfer [Allcock 05] (longer cksums)
  - Petascale storage [Moore 00] (more redundancy)
  - Exascale computing [Reed 04] (any ideas?)

Things Fall Apart

Turning and turning in the widening gyre
The falcon cannot hear the falconer;
Things fall apart; the centre cannot hold;
Mere anarchy is loosed upon the world…

William Butler Yeats
"The Second Coming"

Thank you for your attention. Questions?